The VKL-8301 Multiple Beam Klystron

E. Wright, A. Balkcum, H. Bohlen, M. Cattelino, L. Cox, M. Cusick, E. Eisen, K. Eppley†, F. Friedlander, S. Lenci, J. Petillo†, A. Staprans, B. Stockwell and L. Zitelli
Communications and Power Industries, Microwave Power Products Division
811 Hansen Way, M/S B-450, Palo Alto, CA 94303-0750

†*SAIC, Suite 130, 20 Burlington Mall Rd, Burlington, MA 01803*

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The LC cold option

Advantages

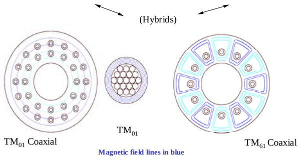
- *Lower operating voltage for a given RF power level.*
- *High efficiency vs. microperveance.*
- *Large instantaneous bandwidths.*
- *Compact, lightweight.*
- *Low Noise.*

Disadvantages

- *Difficult to focus the electron beams; high DC and/or RF body current.*
- *Lower average power (I_{by}).*
- *High cathode loading (some configurations).*
- *Brillouin focusing.*
- *Uniform magnetic focusing field.*
- *Stability.*

There are 2 classes of MBK's*

Fundamental Mode **Higher Order Mode**



Fundamental Mode (FM) MBK

Advantages

- *Large instantaneous bandwidth (TM_{01}).*
- *Low Voltage*

Disadvantages

- *High cathode loading (TM_{01}).*
- *Beams confined by ~$\lambda_o/4$ in diameter (TM_{01}) or radial extent (TM_{01} Coaxial); singly convergent.*
- *Beam interacts with high rf magnetic fields.*

Higher Order Mode (HM) MBK

Advantages

- *High-voltage, high-power operation.*
- ***Low cathode loading**; beam area convergence free of $\lambda_o/4$ constraint.*

Disadvantages

- *Increasingly difficult to focus beams as you move away from geometric centerline.*
- *Electron gun complexity, cost (offset… by J_c).*
- *Narrow-band as a result of the over-moded rf structures used.*

*1) Edward A. Gelvich, Multi-beam amplifiers, NRL Sponsored MBK symposium, 2001
2) A Review of the Development of Multiple-Beam Klystrons and TWT's, G. Nusinovich, B. Levush, D. Abe, NRL/MR/6840--03-8673

MBK selection process

The advantages and disadvantages of each MBK class must be weighed for a specific application.

Common to most vacuum devices is the need for long operational lifetimes (the exception to this rule: expendables).

For mature products, the typical end-of-life failure mechanism is cathode wear-out.

All things being equal, a good starting point is to determine the desired life of the device, which relates directly to cathode loading.

STEP 1: What's important?

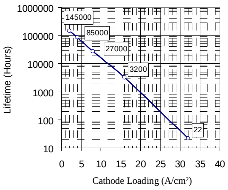
Primary Consideration		First look
Bandwidth	→	FM-MBK
High Power	→	Depends… 2nd Consideration
Maximum Life	→	**HM-MBK**

STEP 2: Where do we want to operate?

M-type dispenser cathode.

Life prediction for fixed heater filament operation, 40 °C above the knee, to 4% degradation in current.

$$L = 281{,}200 \cdot e^{-0.293 \cdot J_C}$$



STEP 3: What constraints do we need to consider?

FM-MBKs (TM_{01} in particular) are constrained by cathode loading, HM-MBK's are not, because:

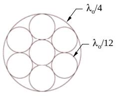
•RF cavity design for the FM-MBK require the beam-cluster to fall within a circle of approximately $\lambda_o/4$.

•Singly-convergent guns must have concentric cathodes and drift tubes.

*Recognizing this, the **best-case** cathode loading for a given current and frequency can be computed.*

$$J_C = \frac{I_o}{A} = \frac{I_o}{\left(\frac{7}{9}\right)\pi\frac{(\lambda_o/4)^2}{4}} = \frac{576}{7\pi}\frac{I_o f^2}{c^2}$$

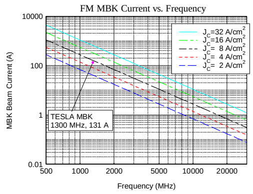
for 19 beams 19/25...



STEP 4: Evaluate

FM MBK approach for TESLA would require cathode loading greater than 7 A/cm².

Our goal was a design with 2 A/cm².



STEP 5: Select

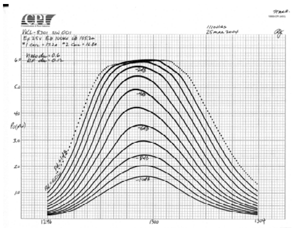
CPI recommends the HM-MBK approach.

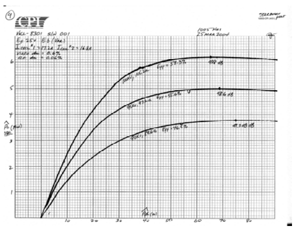
Progress Report

The klystron begin first-test on March 22, 2004.

Several additional weeks of tuning and conditioning will be required before customer source inspection.

Below are some early results showing operation at 6 MW.





Measured Performance

Peak Power Output	9	MW
Ave. Power Output	150	kW
Beam Voltage	115	kV
Beam Current	127	A
DC Beam Transmission	>99.5	%
RF Beam Transmission	98.5	%
Efficiency	61	%
Frequency	1300	MHz
Pulse Duration	20	µs
Saturated Gain	~57	dB

Photo gallery of the VKL-8301 MBK

Modeling and Simulation

A number of design codes were used to model the performance of the VKL-8301 MBK.

Electron Beam Simulation
CPI's XGUN 2.5 D
Michelle 3D

Magnetostatics Simulation
Poisson 2D
S3 – MAFIA 3D
Maxwell 3D

RF Interaction
CPI's LSCEX 1D
CPI's TWODRF 2D
TS3 – MAFIA 3D

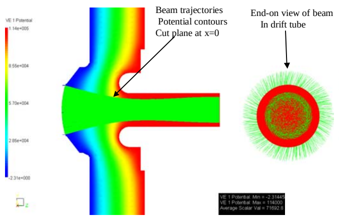
Thermo-mechanical
Ansys 2D and 3D

To the right are some examples of our modeling and simulation results…

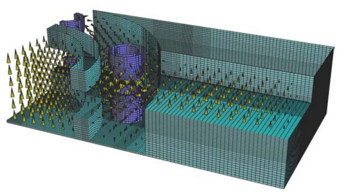
Operating parameters

Peak Power Output	10	MW (min)
Ave. Power Output	150	kW (min)
Beam Voltage	114	kV (typ)
Beam Current	131	A (typ)
Efficiency	65, 67	% (typ, goal)
Frequency	1.3	GHz
Pulse Duration	1.5	ms (min)
Saturated Gain	47	dB (min)
Number of Beams	6	
Number of Cavities	2+3+1	HOM, fund., harm.
Focusing	CFF	
Cathode loading	≤2.5	A/cm² (typ)
Solenoid Power	4	kW (typ)
Length	2300	mm (typ)
Diameter	560	mm (typ, gun)

3D electron gun simulation MICHELLE



3D RF cavity design MAFIA



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